Windows on Orion: A Multi-Wavelength View of the Stars

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TABLE OF CONTENTS

INTRODUCTION

The *light* that we see from the Sun and the *stars* arises within *atoms* and *molecules*, and is called electromagnetic (EM) *radiation*. Its basic property is color, or *wavelength*, which describes the characteristics of the "wave" of light that comes out of the atom or molecule. Each color, or wavelength, carries important information about atoms and molecules, such as their composition and temperature, and astronomers want to study all possible wavelengths to arrive at the most complete understanding of the nature of the stars and other objects in space.

Many of the wavelengths emitted by the stars and other objects in space cannot be seen by our eyes, but we can study these unseen wavelengths with specially designed electronic detectors, such as the one in a video camera. The atmosphere of the Earth interferes with the transmission of much of the radiation that astronomers need to receive at their ground based telescopes. Therefore, satellites are launched into space carrying telescopes which are equipped with the electronic detectors that allow them to gather star light from the regions of the electromagnetic spectrum that are inaccessible from the ground.

The electromagnetic radiation we can see is called **visible light**, but astronomers have given other names to the ranges of wavelengths that can be detected only by electronic devices. They consist of *radio*, infrared, visible, *ultraviolet*, *gamma ray*, and *x-ray* "regions" of the **spectrum** of electromagnetic radiation. In this slide set, we refer to these wavelength ranges as "windows". (Astronomers sometimes refer to "atmospheric windows," which are wavelengths where Earth's atmosphere doesn't interfere very much with the incoming star light, and ground based observations can be made in those wavelength bands. However, for the purposes of this booklet, the term "windows" will refer to the names that have been assigned to the various portions of the electromagnetic spectrum.

Windows on Orion: A Multi-Wavelength View of the Stars is designed to introduce the reader to some of the interesting differences one can "see" when viewing one part of the universe through these many different wavelength ranges, or windows. The constellation of Orion is a well-studied and easily recognized pattern in the sky, so it has been selected as the focal point.

We begin with a look at the constellation of Orion as it has been viewed historically. For thousands of years, humans of all cultures have observed the brightly shining stars of this winter constellation and imagined images of a great hunter, a giant alligator, or other interesting creatures. The first seven slides highlight some of the images that the ancients imagined when gazing at these brilliant points of light and our modern view of how the stars in the Orion pattern are related to each other.

Slides 8 - 29 compare images of the stars and dusty regions of Orion as they appear at different wavelengths. We focus on the part of Orion that makes up the hunter's sword because it has been studied at several different wavelengths. The constellation's cool, *dense molecular clouds* radiate at longer wavelengths and thus appear in the radio and infrared images. In visible images and ultraviolet images, we see the surfaces of glowing stars and *nebulae* that have been heated and *ionized* by nearby stars. X-rays and gamma rays come from energetic processes such as shock waves and material falling onto black holes (although there are no black holes in Orion as far as we know!). Slides 30-38 discuss the nature of the light that we view through the various spectral regions (windows).

The constellation of Orion is relatively nearby, astronomically speaking (the most distant stars in Orion are about 1500 light years away from us), and it is the home of a very special place where the birth of stars occurs. Many of the stars in Orion are not even a million years old. This is very young to astronomers, considering that the Earth is 4,500 million years old and dinosaurs still walked on the Earth about 65 million years ago. The star formation process in Orion is a continuing one–stars are being created in this region of space even now.

NOTE: Words that appear in italics in this text can be found in the glossary.

Slide Captions

1. Orion in Night Sky

This image shows the *constellation* of Orion as we see it with our eyes on a clear winter evening (the lines connecting the stars have been added to the image for descriptive purposes). The constellation sits on the *celestial equator*, so it is visible to star gazers in both the northern and southern hemispheres. From North America, Orion is most easily viewed in the winter evening sky. If one faces south, the constellation is visible around midnight in mid-December, around 10 pm in January, and around 8 pm in February.

In Greek and Roman mythology, Orion was a brave hunter. Three stars (Zeta, Epsilon, and Delta Orionis) form the hunter's belt, and they lie along a diagonal line that is easily seen in the sky. These three bright stars act as pointers for locating two prominent stars in other constellations (not shown in this image). Following the diagonal line to the upper right brings you to Aldebaran (Alpha Tauri), the star that marks the eye of Taurus the Bull. Following the diagonal line of Orion's belt in the other direction brings you to Sirius (in the constellation Canis Major), which is the brightest star in the northern hemisphere sky. Four bright stars outline a rectangle that contains Orion's belt. The upper two of these four stars (called *Betelgeuse* and Bellatrix) form the hunter's shoulders and the lower two (called Saiph and *Rigel*) form the hunter's knees. The brighter of the two shoulder stars, Betelgeuse (also called Alpha Orionis), is a *red supergiant* star that varies in brightness. At its maximum, Betelgeuse (pronounced "beetle-juice") is among the 10 brightest stars in the sky. It is about 300 *light years* away from Earth. Diagonally across from the *variable star* Betelgeuse, in the hunter's leg, you will find a *blue supergiant* star, Rigel. It is the seventh brightest star in the sky and the brightest in Orion. Rigel (also called Beta Orionis) is about 900 light years away from the Earth. A misty patch below the centermost of the three stars that form Orion's belt is known as the *Orion Nebula*, the *Great Nebula* in Orion, or *Messier* 42 (M42). A much smaller and nearly round *nebula*, M43, lies very close to the Great Nebula. Both can be seen with binoculars. A small, reddish nebula (NGC 2024) is close to the belt star Zeta Orionis, which is the lowermost star if the hunter is standing upright. Just south of NGC 2024 is the glowing nebula, IC 434, which is marked by a dark silhouette in the shape of a horsehead (not visible in this image). This *Horsehead Nebula*, as it is often called, is formed by obscuring dust that lies in front of the bright IC 434 Nebula. (Photo © 1993 by Alan Dyer.)

2. Orion in European Culture

In one ancient Greek myth, Orion was a young, handsome hunter. He was the son of Poseidon, the sea god, who bestowed upon his mortal son the power to walk on water. It was not long before Orion's charm caught the eye of Artemis, goddess of the Moon. However, her brother Apollo (the Sun) disapproved of any relationship between his sister and Orion. One day Apollo took his sister to a lake and pointed to what appeared to be a bobbing target. He asked her to hit the target with an arrow. She did, not knowing that the bobbing target was in fact her beloved Orion. In grief, she placed him as a constellation in the winter night sky.

There are many other Greek myths about Orion. This image shows two depictions of how the ancient Greeks may have viewed Orion the hunter. The diagram on the left is drawn after the Greek Cicero. The image on the right is based upon myths from Siberia. Notice the similarities and differences in each, including the direction Orion is facing and weapons he holds. (© *New Patterns in the Sky*, by Julius D. W. Staal, 1988, McDonald and Woodward Publishing Company, Blacksburg, VA, 24060)

3. ORION IN SOUTH AMERICAN CULTURE

Native tribes in South America also looked to the sky and saw the *stars* that make up the *constellation* of Orion. Myths from two of these tribes are shown in this image. To the Bororo Indians of Brazil, the four corner stars of the rectangle in Orion represent the limbs of an alligator known as the Cayman, shown in the left portion of the image. The Cayman, a highly feared animal in the tropical forests, is honored by its postition in the sky. To Peruvians, the middle star of Orion's belt is a criminal whom the Moon Goddess will punish. As illustrated in the right portion of this image, she has sent the two outside stars of the belt, known as Patá, to capture and hold onto the criminal. The criminal will be thrown to the four vultures who wait to devour him. The constellation would, no doubt, strike fear into the hearts of ancient Peruvians and make them behave. (© *New Patterns in the Sky*, by Julius D. W. Staal, 1988, McDonald & Woodward Publishing Company, Blacksburg, VA, 24060)

4. ORION IN EASTERN CULTURE

The group of *stars* that we know as Orion also appears as a *constellation* to Asian cultures. To the ancient Chinese, the constellation shows Tsan-siou, a warrior who bears a striking resemblance to Orion. Tsan's drawn sword, ready to slice off a scorpion's head, is similar to the hunter's club seen in European culture. Tsan-siou was always ready to jump to the defense of Chinese farming villages. (© *New Patterns in the Sky*, by Julius D. W. Staal, 1988, McDonald & Woodward Publishing Company, Blacksburg, VA, 24060)

5. OUR LOCATION IN THE MILKY WAY GALAXY

In order to understand the neighborhood of space that we live in, it is important to think about our relative location in the *galaxy*. Our galaxy, the Milky Way, is a spiral galaxy with arms that curve around a center in the same way the arms of a hurricane circle the eye, as seen in pictures from weather satellites.

This drawing, which shows two views of the galaxy, edge-on and face-on, illustrates where we live in the Milky Way. The Milky Way is a grouping of more than 100 billion *stars*, all clustered together in the form of a pancake with a giant bulge in the center. Our star, the Sun, is just one of those 100 billion stars and all of the stars are in orbit around the center of the galaxy. It takes the Sun (and therefore us) nearly 240 million years to travel just once around our galaxy!

The disk of the Milky Way is about 100,000 light years (LY) across. A *light year* is the distance *light* travels in one year. Our Sun is located in one of the spiral arms of this disk, called the Orion Arm, and it takes light nearly 26,000 years to travel from the center of the Galaxy to the Sun. By contrast, it takes light only about 8 minutes to travel from the Sun to us, which shows the relative size of our solar system to that of the Galaxy. Even though the Sun is 93 million miles away from Earth, it is a lot closer to us than the Solar System is to the center of the Galaxy.

As illustrated here, the newly forming stars in the constellation of Orion are located in the same spiral arm of the Milky Way as our solar system, marked only as the Sun in the drawing. Because the arms of spiral galaxies are places where star formation occurs, it is not surprising to find that many of the stars in the spiral arms are relatively young objects. (Electronic image created by graphic designer Jeff Cruikshank, a student at Prospect High School in San Jose, California. The image was created after that of Abell, Wolff, and Morrison in their textbook, *Realm of the Universe.*)

6. DIAGRAM OF ORION AND ORION MOLECULAR CLOUDS

The *Orion Molecular Cloud*, located within Orion's sword behind the *Great Nebula*, is a region of active *star* formation. This diagram–a composite of carbon monoxide (1 carbon plus 1 oxygen atom, CO) maps superimposed on the prominent visible stars in the Orion *constellation*–outlines both the Northern Molecular Cloud and the Southern Molecular Cloud regions in red, orange, and yellow contour lines. These two massive clouds of gas and dust are each hundreds of *light years* across. In the background, the mythological depiction of Orion the Hunter shows him holding a lion as his shield. As you will discover in the following pictures, we can learn about the details of these clouds and *nebulae* by studying Orion at different *wavelengths.* Carbon monoxide emission is seen at wavelengths longer than those of visible light. (Drawing courtesy of David Faust and the NASA Ames Graphics Department. Original astronomical contour maps courtesy of John Bally.)

7. MODEL OF THE ORION NEBULA

This image shows a model of the *Orion Nebula*, or *Great Nebula*, which is located in front of a *dense molecular cloud* region. We can see the Great Nebula at visible wavelengths with the aid of a small telescope, but the dense molecular cloud must be observed at longer wavelengths. At a distance of only 1,500 *light years*, this active star-forming region is one of the closest to Earth. The Orion Nebula consists of a thin cloud of gas and dust surrounding a few hundred stars all formed within the last million years. The four brightest of these stars are known as the *Trapezium*, so named because they form a trapezoid. The Trapezium stars emit energetic *ultraviolet* light that *ionizes* the hydrogen gas, creating *protons* and *electrons.* This process also heats the gas, making the entire *nebula* glow visibly. The portion of an interstellar cloud where hydrogen has been ionized (stripped of its electron) is called an *HII region* (pronounced H two region). The Roman numeral II is used to distinguish the gas from neutral, atomic hydrogen, which is referred to as HI (pronounced H one). The protons inside an HII region try to recombine with electrons to make neutral hydrogen *atoms* again. However, the constant stream of ultraviolet photons from the young stars continue to break apart any newly formed hydrogen atoms, and the hydrogen usually remains ionized.

The Orion Nebula is actually the

front surface of the dense molecular cloud region that is ionized and set aglow by the Trapezium stars. Although not apparent in this diagram, the dense molecular cloud region is much bigger than the nebula in front of it. The structure of this cloud appears most distinctly in infrared images because the dust in the *molecular cloud* absorbs the high *energy ultraviolet radiation* from nearby stars and re-radiates it at infrared *wavelengths.* The dust is so thick that any visible radiation is absorbed before we can see it. The Orion Nebula and the dense molecular cloud are at different stages of *stellar* evolution. Gravity is causing portions of the dense molecular cloud to contract into clumps of *mass* that form *protostars*, the newest stars of Orion. While the dense molecular cloud is at the very peak of star formation, the Orion Nebula–once a dense molecular cloud itself–has already passed this stage. Its stars have now fully developed and, with the gas and dust now cleared away, the Trapezium stars shine brightly in visible light. (Graphic after B. Zuckerman, UCLA; drawn for *Astronomy: From the Earth to the Universe* by Jay M. Pasachoff, Saunders College Publishing, Philadelphia, 1995.)

8. RADIO IMAGE OF ORION CONSTELLATION

This image shows Orion as it appears at a specific *radio wavelength.* Orion contains two massive clouds of gas and dust. Seen at the bottom right is the Southern Molecular Cloud, which contains the *Orion Nebula* and *Orion Molecular Cloud* 1 (OMC-1). Above it is the Northern Molecular Cloud, which contains the *Horsehead Nebula.* The Northern Molecular Cloud is very close to the lower left *star* of Orion's belt (Zeta Orionis). Optical images show a number of small *nebulae*, as indicated on this image by their names or numbers. Some of these nebulae are regions of *ionized* gas (such as NGC 2024) while others are reflection nebulae (NGC 2023, for example). A reflection nebula is a region of dust illuminated by a nearby star. The *light* from the star is reflected toward us. The colors in this *radio* image indicate relative velocities of the gas in these clouds. A red color indicates gas moving away from us, blue indicates gas moving toward us, and the other colors span the region between the two.

This *false color image* shows the presence of carbon monoxide (CO). Carbon monoxide is a molecule containing one *atom* of carbon and one atom of oxygen. It is easily found on Earth as part of automobile exhaust. The carbon monoxide in Orion and elsewhere in space radiates at a specific radio wavelength or *frequency* and can be detected by radio telescopes. Where there is carbon monoxide, there is also *molecular hydrogen* (H_2). We cannot normally detect molecular hydrogen at the low temperatures found in these clouds, but we can detect the carbon monoxide. Thus, by tracing the location of the carbon monoxide, we can "see" that a large portion of the *constellation* of Orion is actually filled with large clouds of molecular hydrogen. By comparing this radio image with Orion's appearance in *visible light*, you can see that the molecular hydrogen clouds show up clearly at radio wavelengths, yet they do not give off *radiation* at visible *wavelengths.* (Image courtesy of John Bally, University of Colorado.)

9. RADIO IMAGE OF SOUTHERN MOLECULAR CLOUD

This image is a close-up *radio wavelength* view of the Southern Molecular Cloud, a massive cloud of gas and dust that contains *isotopic carbon monoxide* (^{13}CO), a special type of carbon monoxide. The image shows the cool temperature gases found in this region. The colors represent different velocities of the carbon monoxide *molecules* in the gas cloud. The *Orion Nebula*, which appears most clearly in *visible light*, lies in the upper part of the cloud. Notice how much larger the molecular gas cloud is than just the glowing region of the Orion Nebula. The *mass* of this cloud equals a few hundred Suns. (Image courtesy of John Bally, University of Colorado.)

10. IRAS INFRARED IMAGE OF ORION

This *false color image* was constructed from data collected by the Infrared Astronomical Satellite (IRAS). It is a composite image made from data taken at three *wavelengths*: 12, 60, and 100 µm. The warmest features (the stars) are brightest at 12 µm. The interstellar dust is cooler and shines brighter at 60 µm and 100 µm.

The bright yellow region in the lower right of the image is the sword of Orion, containing the *Great Nebula* or Great Orion Nebula (in the Southern Molecular Cloud). Above it and to the left is the nebulosity around the belt star Zeta Orionis (also called Alnitak) that contains the *Horsehead Nebula*. The Horsehead Nebula is barely visible as a small indentation on the right side of the image. Higher and to the left is the reflection *nebula*, M78. The Rosette Nebula, part of the *constellation* Monoceros, is the brightest object near the left margin of the image. This flower-shaped nebulosity is too faint for amateur telescopes, but long exposure photographs reveal its beauty. The *open star cluster* at the center of the Rosette nebulosity (known as NGC 2244) is easily seen with binoculars. Most of the visually bright stars of Orion are not prominent in the infrared. However, *Betelgeuse* can be seen in the upper center of the image as a blue-white dot.

The next slides zoom in for an infrared look at the area in the Southern Molecular Cloud region around the Orion Nebula. (The Infrared Astronomical Satellite (IRAS) was a joint project of NASA, the Netherlands Space Agency, and the Science and Engineering Research Council of the United Kingdom. The IRAS data for this image were processed (or obtained) using the facilities of the Infrared Processing and Analysis Center (IPAC). IPAC is funded by NASA as part of the IRAS extended mission program under contract to JPL.)

11. FAR-IR (60µM) IMAGE OF ORION NEBULA

This infrared image of the *Orion Nebula* was taken aboard NASA's Kuiper Airborne Observatory, an airplane that previously carried a 0.91 meter (36 inch) diameter infrared telescope to altitudes of up to 14 km (45,000 feet). It would not have been possible to obtain this image from the ground, because telescopes on the ground must view the *stars* through the Earth's atmosphere, and water vapor (moisture) in the air absorbs light in the *wavelength* range from about 25 to 300 µm (the *far-infrared*), thereby making ground based observations in the far-infrared impossible. The Kuiper Airborne Observatory is now retired, and astronomers are busy working on the next generation airborne astronomy platform–a Boeing 747 with a 2.5 meter telescope!

This far-infrared 60 µm image was constructed using a special instrument–the Yerkes Observatory 60 element bolometer array–on the Kuiper Airborne Observatory. At 60 μm, dust at temperatures near 50 K is readily detected. The 60 μm observations have a greater contribution from *protostars* than do the observations at shorter wavelengths, because protostars are cool objects and the cooler the object, the longer the wavelength where the maximum amount of light is emitted. The 60 μm *flux* arises from the dust which is heated by nearby stars.

Comparisons between the 60 and 37 μm maps enable astronomers to derive the physical properties of the dust and the far-infrared *luminosity* of the source heating the dust. Both maps have prominent peaks at the embedded BN-KL cluster and strong emission from the *Orion bar* to the south east. However, the tongue of emission that stretches south to southeast of BN-KL in the 37 μm image stretches due south in the 60 μm image. This is because the 37 μm emission is tracing warm dust very near the *HII region/molecular cloud* interface, while the 60 μm flux arises from the somewhat cooler dust that is embedded deeper in the molecular cloud. There also are two prominent clumps of 60 μm emission at the bar that do not show up at all at 37 μm. These clumps are most likely molecular cloud cores that recently began forming stars. (© D.A. Harper, Jr., Yerkes Observatory)

12. FAR-IR (37 μM) IMAGE OF ORION NEBULA

This infrared image of the *Orion Nebula* was taken aboard NASA's Kuiper Airborne Observatory, at an altitude of about 14 km (45,000 feet). It would not have been possible to obtain this image from the ground, because telescopes on the ground must view the *stars* through the Earth's atmosphere, and water vapor (moisture) in the air absorbs light in the *wavelength* range from about 25 to 300 μm (the *far-infrared*), thereby making ground based observations in the far-infrared impossible. This image of the Orion Nebula at 37 μm was obtained with Cornell University's Kuiper Widefield Infrared Camera (KWIC). The visible nebula is powered by the *Trapezium* cluster of very bright young stars. Most of the *luminosity* of the young stars is absorbed by dust in the parent *molecular cloud* and it is then re-radiated in the far-infrared. The 37 μm map traces the total far-infrared luminosity of the source, which tells astronomers how much energy is emitted at those *wavelengths.* The very bright object near the center of the image is the BN-KL cluster of newly formed stars embedded deep in the parent molecular cloud described in the previous image. This cluster emits 25% of the total luminosity of the Orion star formation region, but it is not detectable at visible wavelengths due to *extinction* by dust. There are several other embedded sources in this image as well.

Most of the *radiation* in this image comes from warm dust at the interface between the foreground *HII region* and the parent molecular cloud. The extended features trace the structure of this interface. The linear "bar" feature to the southeast, and the features north of the eastern-most section of the bar are portions of this interface that are brightened because they are presented to us edge-on. Comparisons of the 37 μm and 60 μm images allows the determination of physical parameters such as temperature, *mass*, composition, and size of the dust grains. For example, astronomers now know that there are several isolated sources scattered throughout the image that contain about 1 Jupiter mass of dust! Investigations of clumpy structures are important, because it is the clumps in molecular clouds that ultimately contract to form stars. (Image courtesy of G.J. Stacey, G.E. Gull, T.L. Hayward, H. Latvakoski, and L. Peng, Cornell University, Ithaca, NY.)

13. MID-IR (11.3 μM) IMAGE OF ORION NEBULA

This *mid-infrared* (11.3 μm) slide of the *Orion Nebula* was taken from Mount Lemmon, Arizona. The Orion Bar, *Trapezium*, and the BN/KL regions can be seen from bottom left to top right, respectively. While the emission from the Trapezium and the BN/KL regions comes primarily from dust (at a temperature of about 300 K), the emission at the Bar comes from *ultraviolet fluorescence* of large *aromatic molecules* known as *PAHs* (polycyclic aromatic hydrocarbons). These *molecules* are brightest in the transition zone between the region of intense *ultraviolet radiation*, which *ionizes* hydrogen, and the neutral region to the lower left, which is rich in molecular material. In the *interstellar medium*, PAHs are extremely abundant molecules. On Earth, we see PAHs every day–they are one of the components of auto exhaust (soot) and they are prevalent in the smoke that rises from outdoor grills when the meat fat drips onto the coals. (Image courtesy of Jesse Bregman, NASA Ames Research Center; David Rank and Pasquale Temi, U.C. Santa Cruz.)

14. MID-IR (7.8 μM) IMAGE OF ORION NEBULA

This *mid-infrared* (7.8 μm) image of the *Orion Nebula* was taken aboard NASA's Kuiper Airborne Observatory. The Orion Bar and the *Trapezium* are the prominent features. As in the 11.3 μm slide, the PAH *molecules* produce the emission at the Bar. In the 11.3 μm image, the emission arises from vibrations between the carbon and hydrogen *atoms* on the edge of the molecules, while here the emission is from vibrations between adjacent carbon atoms. The relative positions and brightnesses of the two images give us clues to the sizes of the PAH molecules and to how the molecules are excited by *ultraviolet* light. (Image courtesy of Jesse Bregman, NASA Ames Research Center; David Rank and Pasquale Temi, U.C. Santa Cruz.)

15. NEAR-IR (2.2 μM) GROUND BASED IMAGE OF ORION NEBULA

This image of the *Orion Nebula* was taken, at a *wavelength* of 2.2 μm, with the Ohio State Infrared Imaging System on the Perkins 1.8 meter telescope. The image reveals many luminous objects that are obscured from sight in the visible image of the same region. (OSIRIS image courtesy of B. Ali and D. Depoy of the Ohio State University.)

16. NICMOS CAPTURES THE HEART OF OMC-1

The infrared vision of the Hubble Space Telescope's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) is providing a dramatic new look at the beautiful Orion Nebula which contains the nearest nursery for massive stars. For comparison, Hubble's Wide Field and Planetary Camera 2 (WFPC2) image on the left shows a large part of the nebula as it appears in visible light. The heart of the giant Orion molecular cloud, OMC-1, is included in the relatively dim and featureless area inside the blue outline near the top of the image. Light from a few foreground stars seen in the WFPC2 image provides only a hint of the many other stars embedded in this dense cloud.

NICMOS's infrared vision reveals a chaotic, active star birth region (as seen in the right-hand image). Here, stars and glowing interstellar dust, heated by and scattering the intense starlight, appear yellow-orange. Emission by excited hydrogen molecules appears blue. The image is oriented with north up and east to the left. The diagonal extent of the image is about 0.4 light-years. Some details are as small as the size of our solar system.

The brightest object in the image is a massive young star called BN (Becklin-Neugebauer). Blue "fingers" of molecular hydrogen emission indicate the presence of violent outflows, probably produced by a young star or stars still embedded in dust (located to the lower left, southeast, of BN). The outflowing material may also produce the crescent-shaped "bow shock" on the edge of a dark feature north of BN and the two bright "arcs" south of BN. The detection of several sets of closely spaced double stars in these observations further demonstrates NICMOS's ability to see fine details not possible from ground-based telescopes. [(NICMOS image - Rodger Thompson, Marcia Rieke, Glenn Schneider, Susan Stolovy (University of Arizona); Edwin Erickson (SETI Institute/Ames Research Center); David Axon (STScI); and NASA WFPC2 image - C. Robert O'Dell, Shui Kwan Wong (Rice University)].

17. NEAR-IR MOSAIC IMAGE OF ORION NEBULA

This four-panel sequence shows the Orion Nebula as it appears in four different infrared wavelengths: 2.2 μm (labeled as K-band), 2.167 μm (labeled as HII gas), 3.3 μm (labeled as dust radiation), and 2.12 μm (labeled as H_2 gas). These images were taken from Kitt Peak Observatory in Arizona. Light from the *nebula* enters the telescope and is recorded on detectors (sensors) that are sensitive to specific wavelengths. HII gas represents *ionized* hydrogen, a hydrogen *atom* that has lost an *electron* and become positively charged. H_2 gas is molecular hydrogen, which consists of two hydrogen atoms bonded together.

Two localized spots appear in both the 2.2 μm (K-band) and the 3.3 μm (dust emission) images. The upper of these two is the Becklin-Neugebauer (BN) object. This is a very intriguing source because we see it so clearly in the infrared but not at all in the visible. The central source is so heavily covered up by dust that any *visible light* coming from it would be diminished by a factor of about 10^{30} power before it could reach us. If the Sun were covered up by that much dust, the Earth would experience continuous night. The dust surrounding the BN object absorbs the visible *radiation* that heats the dust grains to temperatures of a few hundred degrees *Kelvin*. The dust grains re-radiate the *energy* in the infrared.

The bright region below the BN object is the Kleinmann-Low (KL) nebula. This nebula contains many compact sources that may be *protostars* or newly formed stars. One of these sources emits more energy than 100,000 Suns, but due to the absorptive dust and gas that enshroud it, it cannot be seen at visual wavelengths. Most of its radiation is absorbed by surrounding dust and re-radiated at wavelengths longer than 30 μm. The BN-KL region is named after four astronomers, using the first letter of each of their last names (Eric Becklin, Gerry Neugebauer, Doug Kleinmann, and Frank Low). (Image courtesy of Ian

Gatley, NOAO.)

18. COMPOSITE IR IMAGE OF ORION REGION

This image shows a picture of the entire *Orion Nebula* as it appears at visible *wavelengths* and an inset image of the Orion Bar region as it appears at three infrared wavelengths. Each of these wavelengths indicates the presence of different *molecules*: molecular hydrogen (green), warm carbon monoxide (red), and complex molecules named polycyclic aromatic hydrocarbons (blue). The Orion Bar is a region of the nebula that receives *energy* from a hot young *star* found nearby. Ultraviolet *radiation* from this star is gradually breaking down the molecular gas in this region, creating what is named an ionization front.

Notice that the three gases shown by the infrared measurements appear layered. This may be because radiation from the star penetrates to different depths of the cloud, destroying the weaker molecules as it encounters them. Unstable molecules stand a greater chance of being broken down by this radiation, but if they are deeper in the cloud they are more protected from the radiation. The infrared data were obtained aboard the Kuiper Airborne Observatory and from ground-based telecopes. (Image courtesy of Alexander G.G.M. Tielens, NASA Ames Research Center.)

19. VISIBLE IMAGE OF ORION CONSTELLATION

This image shows the *constellation* of Orion as we see it with our eyes on a clear winter evening. It was taken with a 35 mm camera with a time exposure lasting six minutes. The three *stars* near the center of the image form a diagonal line (lower to higher if the hunter is standing up) that represents Orion's belt. These stars are called Zeta, Epsilon, and Delta Orionis, respectively. The four bright stars in a large rectangle around this belt form Orion's shoulders (the stars are called *Betelgeuse* and Bellatrix) and his knees (the stars are called Saiph and *Rigel*). Finally, you may be able to make out Orion's sword, a faint glowing region below the middle star in the belt. (Photo © 1993 by Alan Dyer.)

20. VISIBLE IMAGE OF ORION WITH SCHMIDT CAMERA

This image of the Orion Nebula was taken with an 8-inch Schmidt camera by P.C. Crump at the Mauna Kea Observatory in Hawaii. It is interesting to compare this image with the 2.2 µm images of the same region. Many protostars and highly obscured older stars are seen in the longer wavelength 2.2 µm map. In the visible image, the dust completely hides many of those objects. (Image courtesy of Dale P. Cruikshank, NASA Ames Research Center.)

21. VISIBLE (COLOR) IMAGE OF ORION NEBULA

Imagine that a sword hangs from the center of Orion's belt. The three star-like objects that make up the sword can be seen in this *true color image* of the Orion Nebula taken by astronomer David Malin. While the bottom of the three is clearly a star, the top two appear quite fuzzy. They are the regions of gaseous *nebulae*. The middle object marks the location of the Orion Nebula, which is sometimes called the Great Nebula in Orion. This thin cloud of hydrogen gas is about 10 times more massive than the Sun and is spread out over a diameter of 26 *light years*. The hot gas glows because it has been *ionized*, or energized, by *ultraviolet* light coming from the *Trapezium stars.* The Trapezium stars are located in the central region of this nebula. They are overexposed and difficult to see in this image. The ionized gas from the nebula glows brilliantly in the visible region of the spectrum. Behind the Orion Nebula is the dense and much cooler *molecular cloud* that appears in *radio* images and infrared images.

The Orion Nebula, despite its umbrella-shaped appearance, is actually more in the shape of a squat, rounded cigar. From Earth, we see the cigar end on. The Trapezium cluster lies at the center of the Nebula, which appears as a blister on the end of the cigar. (© Royal Observatory Edinburgh/Anglo-Australian Observatory/Photograph by David Malin.)

22. VISIBLE CLOSE-UP OF ORION NEBULA

This image shows a smaller field of view of the *Orion Nebula* region than does the previous slide. Notice the fine details in this swirling, expanding gas cloud. The *ions* of gas are flowing away from the surface of the cloud. We also know that although there are about 500 newly formed *stars* within the nebula, most of the *light* we see comes from the central stars of the *Trapezium*, which are shown in more detail in the next slide. The smaller *nebula* to the north, Messier 43 (M43), is heated by a bright star at its center.

The nearby location (only 1500 *light years*), and the brightness of the Orion region, make it a good target for studies of star formation. The young, brightly shining stars of the nebula have blown off their dusty envelopes, allowing us to see them quite clearly. The nebula seems to be in the final stages of star formation, while the denser cloud of gas and dust behind the nebula is in the prime of its star development. This cloud is also visible at *radio wavelengths* and infrared wavelengths. (©Anglo-Australian Observatory/Photograph by David Malin.)

23. VISIBLE IMAGE OF TRAPEZIUM

This slide shows the four central *stars* of the *Orion Nebula.* These stars are known as the *Trapezium* because they form the shape of a trapezoid. They are located at the very center of the image where they appear as four tightly packed stars. This small clump of stars is the main source of *energy* that illuminates the Orion Nebula. The brightest of the Trapezium stars is 40 times more massive and 300,000 times brighter than the Sun. These stars give off *ultraviolet radiation* that is strong enough to strip *electrons* from the hydrogen *atoms.* When this happens, the gas is said to be *ionized.* When electrons fall back into orbit around the hydrogen atoms, they radiate light in the visible region of the spectrum. In addition, collisions and excitations of oxygen and nitrogen *ions* by electrons produce *visible light.* This is why the *nebula* appears so bright to our naked eye. The nebula would not glow at visible wavelengths if it were not heated and ionized by the Trapezium stars.

Directly behind the Orion Nebula is a *dense molecular cloud* where new stars are being formed. The more massive of these *protostars* will become strong enough to blow away their dust shells and ionize the gases around them, just as in the Orion Nebula today. These stars will further illuminate the region, which will change its shape and brightness over the next hundred thousand years. (©Anglo-Australian Observatory/

Photograph by David Malin.)

24. HUBBLE IMAGE OF ORION NEBULA

This image of the *Orion Nebula* was taken with the NASA Hubble Space Telescope. In this *false color image*, red *light* reveals emission from nitrogen gas; green from hydrogen; and blue from oxygen. The gas in the *nebula* is illuminated by the brightest of the young hot *stars* at the top of the image. Many of the fainter young stars are surrounded by disks of dust and gas that are more than twice the diameter of the Solar System. The great plume of gas in the lower left in this image is evidently the result of the ejection of material from a recently formed star. The *Orion bar* region is seen along the bottom left. The brightest portions are "hills" on the surface of the nebula, and the long bright bar appears to be a long "wall" on a gaseous surface. The diagonal length of the image is 1.6 light years. Just as the *radio wavelength* images revealed the presence of *isotopic carbon monoxide* (^{13}CO) in the cold cloud behind the visible nebula, other ions can be detected at visible wavelengths from the hot nebula. (Image courtesy of Robert O'Dell and Space Telescope Science Institute, STScI.)

25. HUBBLE CLOSEUP OF A "PROPLYD"

This Hubble Space Telescope view shows a smaller portion of the *Orion Nebula* than did the previous image. It reveals five young *stars*. Four of the stars are surrounded by gas and dust that was trapped in orbit about the stars as each star formed. Some astronomers think these gas and dust regions are *protoplanetary disks* or *"proplyds"* that may evolve to form *planets*. The field of view is 0.14 *light years* across. (Image courtesy of Robert O'Dell and Space Telescope Science Institute, STScI.)

26. HUBBLE NICMOS 4 PART IMAGE OF ORION

These are Hubble Space Telescope images of four newly discovered protoplanetary disks around young stars in the Orion nebula, located 1,500 light-years away. Gas and dust disks, long suspected by astronomers to be an early stage of planetary formation, can be directly seen in visible light by Hubble. Disks around young stars (also known as circumstellar or protoplanetary disks) are thought to be made up of 99% gas and 1% dust. Even that small amount of dust is enough to make the disks opaque and dark at visible wavelengths. The dark disks are seen in these images because they are silhouetted against the bright backdrop of the hot gas of the Orion nebula. The red glow in the center of each disk is a young, newly formed star, roughly one million years old (compared to the 4.5 billion year age of the Sun). The stars range in mass from 30% to 150% of the mass of our own Sun. As they evolve, the disks may go on to form planetary systems like our own. While only a handful of these dark silhouette disks have been discovered so far, they seem to belong to a much larger family of similar objects, and current indications are that protoplanetary disks are common in the Orion nebula. Each image is 167 billion miles, or 257 billion kilometers across (30 times the diameter of our own solar system). The disks range in size from two to eight times the diameter of our solar system. The researchers explain the different circular or elliptical shapes as being due to the fact that each disk is tilted toward Earth by different degrees. Each picture is a composite of three images taken with

Hubble's Wide Field and Planetary Camera 2, through narrow-band filters which admit the light of emission lines of ionized oxygen (represented here by blue), hydrogen (green), and nitrogen (red). The hot gas of the background Orion nebula emits strongly at each of these wavelengths, providing a strong backdrop for the disks to be silhouetted against. In each case, the central star is also clearly visible. [Mark McCaughrean (Max-Planck-Institute for Astronomy), C. Robert O'Dell (Rice University) Photo number: STScI-PRC95-45b Hubble Space Telescope.]

27. EXTREME ULTRA-VIOLET IMAGE OF ORION CONSTELLATION

This image, taken with the Extreme Ultraviolet Explorer (EUVE) satellite, shows a large section of the *constellation* of Orion as it appears in the *ultraviolet* region of the spectrum. Cool objects emit *radiation* primarily at *wavelengths* longer than *visible light*, mostly in the radio and infrared. Thus, the cool gas in the *dense molecular cloud* seen in *radio* images and infrared images does not appear in this ultraviolet image. Ultraviolet images reveal information about the hot surfaces of the many newly formed bright *stars* in the region. In particular, notice the three stars of Orion's belt and two bright objects in Orion's sword. The lower of the two sword objects contains the bright stars of the *Trapezium*. These four stars emit ultraviolet radiation that *ionizes* and heats the *Orion Nebula*. The gases of the Orion Nebula then radiate this *energy* at longer wavelengths. (EUVE Image of Orion, courtesy of Isabel Hawkins, UC Berkeley Center for EUV Astrophysics.)

28. X-RAY IMAGE OF ORION CONSTELLATION

This image taken by the Roentgen Satellite (ROSAT) shows the *constellation* of Orion at *X-ray wavelengths*. Similar to the extreme *ultraviolet* image in the previous image, the hot, bright stars of Orion's belt shine clearly at X-ray wavelengths. Again, the cooler *dense molecular clouds* of gas and dust present at longer wavelengths are invisible while *nebulae* in front of the *molecular clouds* in the sword of Orion shine brightly. The X-rays come from very hot gas above the surface of the *star*. Compare this image with both the visible image and infrared image of Orion. (Image courtesy of Konrad Dennerl and Wolfgang Voges, ROSAT team, Max-Planck-Institut für extraterrische Physik, Garching, Germany.)

29. GAMMA RAY IMAGE OF ORION CONSTELLATION

The COMPTEL telescope aboard the Compton Gamma Ray Observatory has detected 3-7 MeV *gamma ray* emission from the Orion Complex, as shown in this slide. This telescope is in orbit around the Earth. The observed emission can be attributed to *spectral lines* that occur at 4.4 and 6.1 *MeV* in *energy*, originating from the decay of energetic cosmic-ray nuclei of carbon and oxygen that bombard interstellar gas clouds. In the map, yellow contours indicate the region of strong gamma ray emission, while blue contours outline the most prominent interstellar gas clouds in the Orion complex. The bright region just visible in the upper right originates from the Crab pulsar in the *constellation* Taurus. (Image courtesy of the Compton Gamma Ray Observatory and the Astronomical Society of the Pacific.)

30. THE ORIGIN OF LIGHT

Electromagnetic *radiation* (EM radiation) is all around us. We are familiar with *visible light* which is EM radiation that we can detect with our eyes. We are also familiar with infrared radiation—the heat you feel coming from a hot stove or warm lamp is EM radiation detected by your skin. There are also other forms of radiation, including *radio waves, ultraviolet, gamma,* and *X-rays.*

One way EM radiation is formed is when a subatomic particle, such as an *electron* or *proton,* loses *energy.* The excess energy is carried away by radiation. The radiation moves through space as electric and magnetic waves that vibrate at right angles to each other and to the direction the wave is moving. All electromagnetic radiation travels through a vacuum at 300,000 km/second, the speed of *light.* Electromagnetic radiation is also described as discrete photons.

This image shows a singe atom. The protons and neutrons of the atom are found in the *nucleus.* Surrounding the nucleus are orbital shells of electrons. The diagram illustrates three types of events in which electrons interact with radiation (photons). In the first case, an electron absorbs the energy of a photon and jumps to a higher energy level. In the second case, the electron falls to a lower energy level and releases a photon. Finally, an electron absorbs so much energy that it leaves the atom altogether. This last process is called ionization. Notice that the smallest changes of energy correspond to low *frequency*/long wavelength waves (red). Ionization requires a large change in energy and is caused by high frequency/short wavelength waves (violet).

In the case of the *Orion Nebula,* ultraviolet *radiation* coming from the *Trapezium* stars *ionizes* hydrogen atoms by stripping their electrons away. Then, as free electrons fall back down into the hydrogen atom electron shells, they release photons in the visible region of the spectrum, making the cloud of gas glow in visible images.

31. ANATOMY OF WAVES

This diagram illustrates the relationship between *wavelength* and *frequency.* Shown here are three waves. Although each travels at the same speed, each has a different wavelength (λ) and frequency (F). Wavelength is the distance from *crest* to crest between one cycle of a wave, measured in distance. Frequency refers to the number of times a wavecrest passes a stationary point in one second. Frequency is measured in cycles/seconds or *Hertz* (Hz). The *energy* (E) of a wave is directly related to its frequency, which means that waves with higher frequencies have higher energies. Further, the energy (E) of a wave is indirectly related to its wavelength, which means that waves with longer wavelengths have lower energies. In the diagram, you can see that the top wave has the longest wavelength (lowest frequency) and, therefore, the lowest energy of the three. The bottom wave is the most energetic of the three, with a very short wavelength (high frequency).

32. THE ELECTROMAGNETIC SPECTRUM

This slide set reveals the Orion constellation at several different *wavelengths*: *radio waves, infrared waves, visible light, ultraviolet* light, *gamma rays,* and *X-rays.* These are all types of different types of EM *radiation,* they simply vary in their frequency and wavelength. For visible light, our eyes detect this difference in color. Blue light has a higher frequency and shorter wavelength than red light. Visible light is the only portion of the EM spectrum that our eyes can detect; however, so we use additional sensors to detect the other regions of the spectrum.

Waves with higher frequency carry more *energy* per *photon* and are generally emitted by hotter sources. Thus, X-rays carry more energy than radio waves. This is important to astronomers because they can gather information about the temperature and composition of an object by looking at the amount of radiation given off at different wavelengths. High energy processes, like the fusion that occurs inside the core of a star, release gamma rays and X-rays. Most stars radiate primarily in the visible and ultraviolet region of the spectrum. All objects emit radiation at wavelengths that are characteristic of the temperature of the object. At 5770 degrees *Kelvin* (the temperature of the Sun's surface), the radiation released by the Sun is mainly visible light. Cooler objects like the dense clouds of gas and dust in the *Orion Molecular Cloud* radiate primarily in the infrared. Human beings are also cool objects and each of us emits a gentle infrared signal. Earth radiates at about 300 degrees Kelvin which peaks at the infrared wavelength of about 10 μm.

Finally, very low temperature objects radiate at the radio end of the spectrum. In the diagram of the EM spectrum, low frequency/long wavelength radiation is on the left while high frequency/short wavelength radiation is on the right. Below the diagram are objects that correspond in physical size to the wavelength listed. (This figure is a modified version of the one that appears in *The Fullness of Space*, used here courtesy of the author, Gareth Wynn-Williams.)

33. TEMPERATURE AND COLOR OF THE STARS

This image illustrates the characteristic *radiation* coming from three *stars* that have different surface temperatures. Each curve (often called the *black body curve*) shows the intensity of radiation (on the vertical axis) for each of the *wavelengths* listed along the bottom (horizontal axis). The three curves represent stars of temperatures equal to 12,000, 6000, and 3800 degrees *Kelvin.* The wavelength of peak intensity is closer to the blue end of the color spectrum for hot stars. Cool stars have radiation peaks at wavelengths that are closer to the red end of the color spectrum.

Rigel is a *blue supergiant* star 25 times more massive than our sun. Massive stars are hotter than the Sun and they burn up their nuclear fuel much more rapidly. At 12,000 degrees Kelvin, Rigel's surface temperature is about twice that of our Sun. The temperature at the surface of the star determines the color we "see". Temperatures deep inside the star are much hotter. For instance, in our sun, the internal temperature reaches 10 million degrees Kelvin, but the surface temperature that determines its yellow color is only 5770 degrees Kelvin. We see *Betelgeuse* as a ruddy, orange star because it has a low surface temperature (3800 Kelvin) that causes the peak intensity of its radiation to fall longward (toward the red) of the wavelength where the Sun's intensity peaks. Notice that our Sun, which is about 5770 degrees Kelvin, peaks directly inside the visible color spectrum. Our eyes, which are simply electromagnetic radiation detectors, are matched perfectly to pick up the peak radiation coming from our light source, the Sun. Think about the possibilities if life developed around a star with a temperature different from that of the Sun. The radiation detectors of those life forms would probably be sensitive to a different peak radiation *wavelength*, which might not be in the visible portion of the electromagnetic spectrum at all!

34. DENSE MOLECULAR CLOUDS

Dense Molecular Clouds are regions of space that contain large quantities of hydrogen and helium gas, as well as tiny dust grains made of sand and soot. The dust grains are covered by layers of ice that contain organic *molecules*. The ices are made up of materials other than ordinary water, and complex chemistry occurs when the cloud breaks up and the icy grains are heated. When this happens, chemical bonds begin to break and reform into new molecules. Some organic molecules (carbon bearing molecules that are associated with life) are probably made in such a manner. We see the evidence of organic molecules in intersteller space—they are distributed widely throughout our own *galaxy* as well as other galaxies. (Image courtesy of Y. Pendleton.)

35. THE FORMATION OF A STAR

This schematic diagram shows *protostars* forming within a *molecular cloud*. All *stars* are affected by two main forces: gravity, which makes the cloud collapse in on itself to form a star; and pressure, which supports the cloud against gravity. Initially, the inward pull of gravity is stronger than the outward push of pressure and the cloud collapses. As the interior of the cloud cools and the gas pressure drops, matter begins to collapse upon itself due to gravity. As the collapse proceeds, the center becomes warmer and denser. Eventually, nuclear fusion begins which releases large amounts of *energy*. As the temperature and pressure increase, the process of *gravitational* collapse is halted and a star is born! (Image courtesy of Y. Pendleton.)

36. LIFE CYCLE OF A LOW MASS STAR

This image shows the typical life cycle for a low mass *star*. Low mass stars last for several billion years, steadily converting hydrogen into helium. This cycle also produces elements like carbon, nitrogen, and oxygen. At the end of their lifetimes, these stars lose *mass* as layers of matter are pushed away from the surface of the star. The layers of matter contain *atoms* of hydrogen, carbon, oxygen, and nitrogen that sometimes join together to form *molecules*. These molecules go out into the *interstellar medium* (ISM), the region between stars, where they are dissociated (broken apart) and possibly ionized (stripped of *electrons*). As time goes on, the interstellar gas (and the next generation of stars and *planets*) contains more and more of these elements. Eventually, stars and planets are formed out of gas and dust. Most stars have low masses (similar to that of the Sun) and are long-lived (about 10 billion years). A few stars are very massive (50 times that of the Sun) and live only briefly (a million years). As you can imagine, there is a whole range of masses and corresponding *stellar* lifetimes in between the low mass and high mass examples. (Image courtesy of Y. Pendleton.)

37. LIFE CYCLE OF A HIGH MASS STAR

This diagram shows a typical life cycle for a high mass *star*. High mass, or “massive” stars are hotter than low mass stars because their internal pressures are so great. They burn their fuel more quickly than do low mass stars. The life cycle of such a star begins when the dense hydrogen gas near a young massive star becomes completely *ionized* due to the stream of *ultraviolet photons* coming from the star. This ionized gas, called an *HII region*, has higher densities (*atoms* per cubic centimeter) and much higher temperatures than the gas surrounding it. The surrounding gas is either in the form of *molecular hydrogen* (H_2) or neutral, atomic hydrogen (HI). Eventually, the much greater pressures of the HII region will cause it to expand into the neighboring gas. The "push" that the neighboring gas atoms and *molecules* receive causes them to move more quickly, probably up to speeds of 10 km/sec. The expansion of the HII regions into neighboring regions might cause other parts of the cloud to become unstable and to collapse in on themselves. In this way, new stars are born. Eventually, massive stars end in a *supernova* explosion. The new heavy atoms, such as carbon, oxygen, and silicon, formed as the star was burning its nuclear fuel and during the explosion itself, are released into the *interstellar medium* (the region between the stars) and are eventually incorporated into other *dense molecular clouds* from which new stars are born. Rare elements such as gold, silver, lead, and uranium are formed in small quantities in the supernova explosions. They are not only rare on Earth, but throughout the universe. (Image courtesy of Y. Pendleton.)

38. STELLAR EGGS

This spectacular image was taken with the Hubble Space Telescope. It is of the Eagle Nebula (M16) which is located about 7000 *light years* away from us (between the *constellations* of Sagittarius and Serpens). While it is not a part of the Orion constellation, it has been included in this slide set to illustrate the star formation process from a different view. Dr. Jeff Hester, from Arizona State University, and his colleagues obtained this beautiful image in April 1995. For the first time ever, astronomers now see details of the cocoons in which some *stars* are born. The *nebula* is a "bowl-shaped" blister on the side of a *dense molecular cloud*, much like the one seen in Orion. However, in Orion we may be viewing the tips of the finger-like projections end on so that we do not see the columns of gaseous material shown here. About 100 young stars are inside the bowl in the Eagle nebula. Radiation from these stars heats up the gas cloud and causes some of the gas to evaporate in long streams which go into space. The streams, or columns, contain more of the denser material such as carbon and silicate dust than is found in the *molecular cloud*. The bumps on the ends of the finger-like projections are about the size of our solar system. These regions are even more dense than the rest of the "finger". They are dense enough to start the collapse process that leads to the production of new stars. Astronomers call these formations "evaporating gaseous globules"—or EGGs. (Image courtesy of Dr. Jeffrey Hester and Space Telescope Science Institute, STScI.)

RELATED WEBSITES

ASTRONOMY GENERAL EDUCATIONAL SITES

Space Telescope Science Institute:
http://www.stsci.edu/exined

Astronomy and Space Sciences
http://www-hpcc.astro.washington.edu/scied/astro/astroindex.html

The Astronomy Cafe
http://www2.ari.net/home/odenwald/cafe.html

Astronomy Picture of the Day
http://antwrp.gsfc.nasa.gov/apod/astropix.html

HST Images by Subject
http://oposite.stsci.edu/pubinfo/SubjectT.html

sci.astro (astronomy)

sci.edu (science education)

ORION NEBULA

APOD Search Results for "orion nebula"
http://antwrp.gsfc.nasa.gov/cgi-bin/cossc/apod_search?orion+nebula

Doug Johnstone's Orion Page
http://www.cita.utortonto.ca/~johnston/orion.html didn't work 8/21/97

Orion Nebula
http://www.lifeintheuniverse.com/orionneb.html

The Orion Nebula
http://www.astro.lsa.umich.edu/users/iotm/oct95/orion.html

Orion the Constellation: Guided Tour
www2.ari.net/kcox/starparty/constellation/oristory/oristory.html

STAR FORMATION

Birth of Stars
http://www.herts.ac.uk/astro_ub/a35_ub.html

Star Facts: January 1996 Article
http://www.ccnet.com/odyssey/sfa0196.html

Star Formation Regions
http://www.astro.ucla.edu/irlab/star.html

What is a Star?
http://www.ast.cam.ac.uk/pubinfo/leaflets/star/star.html

Astronomical Spectroscopy
http://www.ast.cam.ac.uk/pubinfo/leaflets/spectroscopy/spectroscopy.html

Electromagnetic Spectrum
http://observe.ivv.nasa.gov/nasa/education/reference/emspec/emspectrum.html

The Electromagnetic Spectrum
http://heasarc.gsfc.nasa.gov/docs/learning_center/museum/exploratorium/emspectrum.html

Lesson Plan on the Electromagnetic Spectrum
http://sd-www.jhuapl.edu/NEAR/Education/lessonSpectrum/lpspec.html

GLOSSARY

ACCELERATE
To make any change in motion by changing either speed or direction. Slowing down, speeding up, turning left, and turning right are all accelerations.

ÅNGSTROM (Å)
A unit used to measure wavelengths where 1Å = 1 ten-billionth of a meter (see also *wavelength*).

AROMATIC MOLECULES
see *PAHs*

ASTRONOMICAL UNIT (AU)
A unit to measure distances, especially within solar systems. 1 AU = 149.6 million kilometers, the distance from the Earth to the Sun.

ATOM
An atom is made up of a nucleus with protons and neutrons, orbited by electrons. An atom generally has a size of about 1 Ångstrom (see also *electron, proton, Ångstrom*).

BECKLIN-NEUGEBAUER (BN) OBJECT
An object located behind the Orion Nebula that was discovered by astronomer Eric Becklin and Gerry Neugebauer. This object may be a single hot star formed within the last 100,000 years that is surrounded in so much gas and dust that we cannot see it visibly. However, the heated gas and dust around it glows strongly in the infrared.

BETELGEUSE
A red supergiant star, also called alpha Orionis, representing one of shoulders of the constellation of Orion. It is a semi-regular variable star that fluctuates between 0.4 and 1.3 magnitudes in brightness with no fixed period. At its brightest, Betelgeuse is one of the 10 brightest stars in the sky. It is about 300 light years away from the Earth, and it is not physically related to the region where star formation is ongoing.

BLACK BODY CURVE
The plot of intensity versus wavelength (or frequency) that would be produced by a body that absorbs and then re-emits all the energy that falls upon it.

BLUE SUPERGIANT
Extremely bright, hot, and large stars; a post main-sequence stage of evolution of stars with mass greater than four times our sun's mass. These stars are hotter than red supergiants.

BN-KL CLUSTER
see *Becklin-Neugebauer object* and *Kleinmann-Low Nebula*

CELESTIAL EQUATOR
The projection of the Earth's equator onto an imaginary sphere around the Earth (the celestial sphere). The stars appear to be fixed on the celestial sphere.

CONSTELLATION
A pattern of stars in the sky named after a person, animal, or object. The sky is divided up into 88 areas known as constellations. The stars in a constellation are most often at vastly different distances from us, but they appear to be relatively close to each other in the sky from our point of view.

CREST
The top or peak of a wave.

DENSE MOLECULAR CLOUD

A collection of cold gas (mainly molecular hydrogen at about 10 degrees Kelvin) and dust where star formation occurs. These clouds have sizes of many hundreds or thousands of astronomical units (see *astronomical unit*).

EGGS

Evaporating gaseous globules that appear to be the stellar cocoons out of which stars hatch.

ELECTROMAGNETIC RADIATION (EM RADIATION)

A form of energy that involves a vibration in the electric field and magnetic field. This radiation arises whenever a subatomic particle loses energy and emits a photon. All EM radiation travels through a vacuum at the speed of light (300,000 km/sec). Examples of EM radiation include radio waves, microwaves, infrared waves, visible light, ultraviolet light, X-rays, and gamma rays.

ELECTROMAGNETIC SPECTRUM (EM SPECTRUM)

The ordered array of electromagnetic radiation, involving radio waves (longest wavelength), microwaves, infrared waves, visible light, ultraviolet light, X-rays, and gamma rays (shortest wavelength). Each of these regions of the spectrum is described in more detail in this glossary.

ELECTRON

A subatomic particle, negatively charged, that moves around or between the nuclei of atoms (see also *atom*, *nucleus*).

ENERGY

A fundamental quantity usually defined in terms of the ability of a system to do work. An example is the ability to move an object by application of a force.

EXTINCTION

The dimming of light as it passes through some material such as the Earth's atmosphere or the interstellar medium.

FALSE COLOR IMAGE

An image in which the colors have been artificially assigned to different regions in order to illustrate the contrast between them. The color is not produced by the physical situation being observed.

FAR-INFRARED

That part of the electromagnetic spectrum that has a wavelength greater than the mid-infrared and shorter than the radio region.

FLUORESCENCE

The process by which a high energy photon is absorbed by an atom and re-emitted as two or more photons of lower energy.

FLUX

Energy emitted by an astronomical body at a specific wavelength.

FREQUENCY

The number of waves that pass a certain point per unit of time.

GALAXY

A grouping of billions of stars held together by gravity. Galaxies, which are classified by their shapes, are labeled irregular, elliptical, or spiral.

GAMMA

see *gamma ray*

GAMMA RAY
Highly penetrating photon of EM radiation with a very short wavelength (10^{-12} METERS)(see also *wavelength*).

GRAVITATION
The mutual attraction between two masses.

GREAT NEBULA
see *Orion Nebula*

HI REGION
A region in space where the hydrogen gas is primarily in the neutral, atomic state (one proton and one electron).

HII REGION
A region in space where the hydrogen is ionized (stripped of its electron). A zone of hot, ionized hydrogen in interstellar space; it usually forms a bright nebula around a hot, young star or cluster of hot stars.

HERTZ (HZ)
A unit measuring one cycle or wave per second.

HORSEHEAD NEBULA
A cloud of dust that overlies the tenuous nebulosity called IC 434, which stretches southward from Zeta Orionis (the lower left star in Orion's belt). The dust produces a dark region which looks like a horsehead. With even the largest amateur telescopes this is a difficult object to observe. Long exposure photographs provide us with the beautiful images that are commonly associated with the Horsehead Nebula.

INFRARED WAVES (IR RADIATION)
Electromagnetic radiation with wavelengths longer than that of visible light and shorter than millimeter radio waves (see also *electromagnetic radiation*).

INTERSTELLAR MEDIUM (ISM)
The region of space between the stars that is occupied by gas and tiny, solid dust particles.

ION
An atom electrically charged because of the loss or gain of an electron (see also *atom, electron*).

IONIZE
To make an ion by adding or removing electrons from an atom.

IONIZED HYDROGEN (HII)
A hydrogen atom that has lost its electron and become positively charged (a proton).

ISOTOPE
One of two or more atoms whose nuclei have the same number of protons but different numbers of neutrons (see also *nucleus, proton*).

ISOTOPIC CARBON MONOXIDE (^{13}CO)
A molecule containing one atom of oxygen and one atom of carbon-13, which is a carbon atom with one extra neutron. (see also *isotope*).

K-BAND
A region of the near-infrared spectrum centered at a wavelength of 2.2 µm.

KELVIN (K)
A temperature unit with the same sized divisions as the Celsius scale. There are no negative numbers in the Kelvin scale, as zero degrees Kelvin equals absolute

zero, the point at which no more energy can be extracted from a substance and no further lowering of its temperature is possible (0°K = -273°C = -460°F).

KLEINMANN-LOW (KL) NEBULA
A region of the dense molecular cloud behind the Orion Nebula that was discovered by astronomers Doug Kleinmann and Frank Low. This region contains many compact sources that may be protostars or newly formed stars. This object glows very brightly in the infrared.

LIGHT
Electromagnetic radiation that is visible to our eyes (see also *electromagnetic radiation*).

LIGHT YEAR (LY)
Distance traveled by light in a vacuum in one year: 1 light year = 9.46×10^{12} kilometers, or about 6×10^{12} miles.

LUMINOSITY
The total energy emitted by an object per second.

MASS
A measure of the total amount of matter in a body or particle.

MEGA-ELECTRON VOLT (MEV)
The energy gained by a proton in dropping through a potential difference of 10^6 volts. In frequency units, 1 electron volt (eV) is equivalent to 8023 cm^{-1}, and 1 MeV is equivalent to about 10^{20} Hertz.

MESSIER
Nomenclature for naming celestial objects.

MICROMETER (µM)
A unit of length (1 micrometer = 1 millionth of a meter). Also referred to as µm.

MID-INFRARED
That portion of the electromagnetic spectrum that lies between the shorter wavelength infrared and the longer wavelength far-infrared (typically between 5 and 50 µm).

MILKY WAY
The spiral-shaped galaxy in which the Earth (and the entire Solar System) is located. The Milky Way is one of billions of galaxies in the universe (see also *galaxy*).

MOLECULAR CLOUD
see *dense molecular cloud*

MOLECULAR HYDROGEN (H_2)
The form in which the element hydrogen exists in molecular clouds. Molecular hydrogen consists of two hydrogen atoms bonded together, which occurs primarily at low temperatures.

MOLECULE
Two or more atoms bound together (see also *atom*). Examples are H_2 and CO.

NEBULA
Bright cloud of optically visible gas or dust observed in interstellar space.

NEUTRON
A subatomic particle with no electrical charge and a mass nearly equal to that of the proton. Neutrons and protons are the main components of the atomic nucleus.

NGC
Nomenclature for naming celestial objects. NGC stands for New General Catalog of Nebulae and Star Clusters.

NUCLEUS
The central part of an atom, made up of protons and neutrons, about which the electrons move (see also *atom, electron).*

OPEN STAR CLUSTER
A small group of stars (up to a few hundred) that are gravitationally bound together, primarily found within the plane of the galaxy. The stars in these clusters differ from those found in globular clusters in the halo of the galaxy in that open cluster stars include many young stars that have a greater abundance of heavy elements than do the older, earlier generations of stars found in the halo.

ORGANIC
Involving carbon compounds.

ORION BAR
A region in the Orion Nebula that is a condensation of material in a barlike pattern; the emission from the Bar comes from ultraviolet fluorescence of large aromatic molecules known as PAHs (polycyclic aromatic hydrocarbons).

ORION MOLECULAR CLOUD
see *Orion-A/Orion-B Molecular Clouds*

ORION NEBULA
A thin cloud of gas and dust surrounding a few hundred stars all formed within the last million years. The brightest of these stars, the Trapezium, ionize the gases, making them glow visibly. To the naked eye, the Orion Nebula (also called the Great Nebula and Messier 42) appears as a fuzziness surrounding the middle star of Orion's sword. It is located in the upper portion of the Southern Molecular Cloud. The Orion Nebula appears greenish to the human eye, but photographs show that it is actually reddish-orange. The human eye has poor sensitivity to colors at low light levels.

ORION-A/ORION-B MOLECULAR CLOUD
Also known as the Southern and Northern Molecular Clouds, respectively.

PAHS
Polycyclic aromatic hydrocarbons; five carbon atom rings with hydrogen attached to the sides.

PHOTON
The basic packet of electromagnetic radiation that comprises light. A photon is emitted from an atom when an electron changes orbits or energy levels.

PLANET
A large body (greater than about 1000 km across) that is in orbit in a stellar system (see also *star*). It is a body with insufficient mass for nuclear reactions to begin.

PROPLYD
see *protoplanetary disk.*

PROTON
A subatomic particle, positively charged, that is found in the nuclei of atoms (see also *atom, nucleus*).

PROTOPLANETARY DISK
The disk-shaped cloud of material orbiting a star from which planets are formed. These are sometimes called proplyds (see also *planet, star*).

PROTOSTAR
A young star that shines because of the energy of the infalling material, rather than from the nuclear fusion that dominates the energy supply for a star. Protostars have sizes on the order of 0.01 to 0.1 astronomical unit (see *astronomical unit*).

RADIATION
Energy that travels in the form of photons, which can move through a vacuum (see also *energy*).

RADIO
see *radio wave*

RADIO WAVE
Electromagnetic radiation with a wavelength longer than about one millimeter.

RED SUPERGIANT
Extremely bright, cool, and larger stars; a post main-sequence stage of evolution of stars with mass greater than four times our sun's mass.

RIGEL
A blue supergiant star representing one of the knees of the hunter in the constellation of Orion. Rigel is 800 light years away and it is not related to the region of star formation.

SPECTRAL LINE
The appearance of a peak in the energy spectrum of a star or other sources of light that corresponds to a specific molecule or atom that is present.

STAR
A sphere of gas that shines due to nuclear fusion reactions in the interior.

STELLAR
see *star*

STELLAR WIND
Outflow of gas, either steady or sporadic, that comes from the corona of a star.

SUPERNOVA
Phenomenon in which a massive star, at the end of its nuclear burning life, increases its energy output several billion fold for a short time. Some supernovae become as bright as the whole galaxy in which they are observed.

SUPERNOVA REMNANT
The gaseous remainder of the star destroyed in a supernova. Detectable at radio wavelengths, these remnants travel through the interstellar medium at high speeds.

TRAPEZIUM
A group of four bright, young stars found in the Orion Nebula, named because their location forms a trapezoid on the sky. These young, massive, hot stars ionize the gas around them.

TRUE COLOR IMAGE
Colors in an image that are actually produced by the physical conditions at the site.

ULTRAVIOLET (UV)
Band of electromagnetic radiation from about 40-4000 Å (see also *Ångstrom, electromagnetic radiation*).

VARIABLE STAR
Any star whose luminosity changes over a short period of time.

VELOCITY
The speed and direction in which distance is covered over time.

VISIBLE LIGHT
Electromagnetic radiation emitted between 4000 and 7000 Å (see also *Ångstrom, electromagnetic radiation*).

WAVELENGTH
The distance between two successive crests or troughs of a wave.

X-RAY
High energy electromagnetic radiation with wavelengths of about 10^{-10} meters.

About the Author

Dr. Yvonne Pendleton is an astrophysicist at NASA Ames Research Center in Moffett Field, CA. She received her Ph.D. in Astrophysics from the University of California at Santa Cruz. Her area of expertise is infrared observational astronomy which allows her to study the composition of interstellar dust and how it becomes incorporated into young stellar and planetary systems. She is interested in the origin of life on Earth and the possibility of life on other worlds. In addition to her scientific research programs, Dr. Pendleton participates in several educational outreach programs, including Project ASTRO sponsored by the Astronomical Society of the Pacific.

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